

THE USE OF COMPENDIA, DESIGN MANUALS, AND REFERENCE TEXTS IN PREDICTION
OF NONNUCLEAR WEAPONS EFFECTS

W. E. Baker

Southwest Research Institute

ABSTRACT

The literature on nonnuclear weapons effects dates from the 16th century, is extensive, is widely scattered, and includes many classified references. This diffusion presents problems to both neophytes and experts in this field -- the neophyte can be overwhelmed by the volume of the literature, and unable to choose between conflicting references or prediction methods; while the "expert" may be expert in only a narrow specialty in weapons effects, and not truly conversant with other specialties. So, a limited library of broad references on the symposium topic can be very useful.

The broad references include compendia, design manuals and general reference texts. They give rather broad coverage, but the topics covered, depth of coverage, and accuracy and depth of reference to the literature vary considerably between the references. The paper will discuss the coverage of each cited general reference, will note the depth or lack of depth of literature reference, and will also give a brief evaluation of the reference.

INTRODUCTION

Nonnuclear weapons effects include at least the effects on a wide variety of targets of: explosions and shock waves in air, water and the ground; impacts of penetrating projectiles and fragments; penetration by high-speed jets; incendiaries; smokes; and a variety of chemical agents. The spectrum of past, present and future weapons is very broad. The spectrum of "targets" is also very broad. Weaponry is an ancient discipline, and is also highly nationalistic. All of these factors combine to render the literature on the symposium topic voluminous, secretive and very diffuse.

If you are a neophyte to weapons effects, you can easily be overwhelmed by the extensive literature, and inconvenienced by the security classification of some of it. Even if you have been working in this field for many years, you may be rather unaware of some types of weapons effects, and are also inconvenienced by security restrictions.

We have found over the years that your work can be somewhat eased by using a limited basic library of unclassified references which contain useful technical discussions, data bases and/or analysis and prediction methods for a variety of weapons effects. Some of these broad references are obvious and well-known; others are not. We have found

some to be much more useful than others. Some have been quickly outdated, while others retain remarkable usefulness after many years.

This paper presents the author's suggestions for a limited library of broad references which can be useful in describing and evaluating nonnuclear weapons effects. Only unclassified references are included in the list. All were at one time easy for anyone to acquire, but some may now be quite difficult to get. We review in this paper only references in English.

The broad references are divided into three categories, i.e., compendia, design manuals and reference texts. They are discussed in that order. For each reference, we identify it, and then briefly discuss those contents relating to weapons effects. Depth of literature coverage is noted, as are strengths or shortcomings. Usually, the discussion is the author's but in some instances, reviews by others are substituted. When this is done, the review is in quotes, and the name of the reviewer is included.

The paper includes a brief closure, which includes some discussion on availability of these references.

DISCUSSION OF COMPENDIA

Because compendia usually consist of groups of papers or chapters by different authors, the adequacy of coverage of specific topics tends to vary considerably from chapter to chapter. But, there are some exceptions to this rule in our list, as noted.

White, M. T. (Editor) (1946), Effects of Impacts and Explosions, Summary Technical Report of Division 2, National Defense Research Council, Volume 1, Washington, D.C., AD 221-586. (Ref. 1)

Although this reference is rather old, it is a thorough review of U.S. research studies during World War II on explosions in air, water, and earth; ballistic impact effects on steel, concrete, and soil; gun muzzle blast; dynamic materials properties; protection against various weapons effects; and target analysis and weapon selection. Some of the Weapon Data Sheets included in the compendium, particularly those on penetration of projectiles into various media, are useful. The reference list is extensive.

The discussions and descriptions in this work are very clear and readable, and some of the compiled and scaled test data are still the most definitive available. Unlike many other compendia, treatment of all topics, by the various authors, is excellent and thorough. This is a must for your reference shelf.

Annals of the New York Academy of Sciences (1968), Volume 152, Article 1, "Prevention of and Protection Against Accidental Explosion of Munitions, Fuels and Other Hazardous Mixtures," October 28, 1968. (Ref. 2)

This is a very unusual source giving information on accidental explosions and their effects, but this one volume of the *Annals* contains a wealth of useful information in papers contributed by many researchers and safety engineers from the U.S. and Europe. The quality of the individual papers ranges from excellent to fair. Most of them reference the literature well, but a few omit a number of key references to prior work on the paper topic. The sections most applicable for predicting weapons effects are Part II. Personnel Sensitivity; Part III. Sensitivity of Explosive Materials, and Part IV. Explosive Effects.

Swisdak, M. M., Jr., "Explosion Effects and Properties: Part I - Explosion Effects in Air," NSWC/WOL/TR 75-116, Naval Surface Weapons Center, White Oak, Silver Spring, Maryland, Oct 1975, AD A018 544. (Ref. 3)

This is an excellent compendium giving properties of air blast waves from nonnuclear weapons. The emphasis is on presentation of graphs and equations, and on example problems for their use. Included also are data on air blast from shallow underwater and underground explosions, and cratering for buried explosions. The compendium is based primarily on work in U.S. Navy laboratories, and this is well referenced. A weakness is that the extensive related work by U. S. Army, U. S. Air Force and foreign sources is largely ignored.

Swisdak, M. M., Jr., "Explosion Effects and Properties: Part II - Explosion Effects in Water," NSWC/WOL/TR 76-116, Naval Surface Weapons Center, White Oak, Silver Spring, Maryland, Feb 1978, AD A056694. (Ref. 4)

This is the counterpart to the preceding compendium, but for underwater explosion effects. The type of coverage is similar, with coverage of similitude relations, underwater shock wave parameters for shallow and deep explosions, bubble pulse characteristics, underwater shock from line charges, and related topics. This compendium should be considered as a supplement to Cole's book, Underwater Explosions, which will be discussed later. The literature is well referenced.

"Behavior and Utilization of Explosives in Engineering Design and Biochemical Principles Applied to Chemical Medicine," Proceedings of the 12th Annual Symposium American Society of Mechanical Engineers, New Mexico Section, March 1972. (Ref. 5)

The first part of this compendium includes a number of well-written papers on detonation of explosives and their utilization. Its value lies in good descriptions of explosive processes, how explosives accelerate materials, and how materials respond to intense explosive loading. Most of the papers are excellent, and well-referenced.

Doering, W. and Burkhardt, G., "Contributions to the Theory of Detonation," Translation from the German as Technical Report No. F-TX-1227-1A (GDAM A9-T-4G), Headquarters, Air Material Command, Wright-Patterson AFB, Ohio, May 1949, AD 77863. (Ref. 6)

Much of the German work during World War II on detonation of explosives, and shock transmission through air, water, and at interfaces between media is included. The treatment is very lucid, even in translation. Reference is, of course, almost exclusively to German work. One of its most useful aspects is the presentation of equations for predicting shock strengths on reflection from or transmission between different media.

DISCUSSION OF DESIGN MANUALS

There are available a number of manuals for prediction of explosion and impact loads on structures, and design of structures to resist such loads. Most are intended for use by structural engineers, and they concentrate heavily on presentation of design equations and graphs. A number of weapons effects can be predicted from information in most of the manuals.

U. S. Army Material Command, Engineering Design Handbook: Principles of Explosive Behavior, AMC Pamphlet AMCP 706-180, 1972. (Ref. 7)

This is one in an extensive series of Army design manuals. It includes very thorough, well-written, and well-referenced material on the detonation physics of explosives. It will not allow you to numerically predict many weapons effects, but it should give you a good understanding of the physical processes occurring when explosives detonate.*

"Fundamentals of Protection Design (Non-Nuclear)," Department of the Army Technical Manual, TM 5-855-1, Department of the Army, July 1965. (Ref. 8)

This was one of the first design manuals for protective structures. It was based on work by MIT and University of Illinois structural engineers, and includes some information useful in estimating weapons effects. Like some other manuals, a weakness is inclusion of only a bibliography, and not specific references. It has now been superseded by later manuals.

*The Army Engineering Handbook Series includes several other manuals which are very useful in predicting weapons effects, but they are classified and so do not qualify for our list.

"*Suppressive Shields Structural Design and Analysis Handbook*," U.S. Army Corps of Engineers, Huntsville Division, HNDM-1110-1-2, 1977. (Ref. 9)

Suppressive shields are structures (usually vented) designed to arrest fragments and attenuate blast and fireball effects for accidental explosions in munitions plants. This manual includes a number of topics which can be quite useful in estimating weapons effects, including prediction methods and data for free-field blast waves, blast loading of structures, internal explosion blast and gas pressure loads, and fragment impact on structures. Presentation is clear, and sources are well referenced.

Crawford, Robert E., Higgins, Cornelius, J., Bultmann, H., "The Air Force Manual for Design and Analysis of Hardened Structures," Report No. AFWL-TR-74-102, Contract No. F29601-74-C-0018, Civil Nuclear Systems Corporation, Albuquerque, New Mexico, October 1974, Second Printing October 1976. (Ref. 10)

This manual is intended for design to resist nuclear weapons effects, but it still contains material useful in estimating some nonnuclear effects. The useful parts are those on air blast phenomena, and ground shock and cratering. The treatment of structural response and damage largely repeats that in Ref. 9 and 20. Referencing is extensive and good.

Structures to Resist the Effects of Accidental Explosions, Department of the Army Technical Manual TM 5-1300, Department of the Navy Publication NAVFAC P-397, Department of the Air Force Manual AFM 88-22, Department of the Army, the Navy, and the Air Force, June 1969. (Ref. 11)

This design manual is the "Bible" for most structural engineers involved in blast-resistant design in reinforced concrete. Its strengths are in presentation of detailed procedures for estimating blast loading for internal explosions, failure modes for reinforced concrete, structural elements, and design of reinforcing. Basic structural design procedures are identical to those presented earlier by MIT authors.

There are data and prediction methods for estimating free-field blast wave properties, internal and external blast loads on structure, fragment impact effects on structures, and blast effects on humans. Descriptions of blast loading and its effects are quite good. A weakness is complete lack of referencing, although there is a reasonably complete bibliography.

This manual is now being revised and updated. Unfortunately, the weaknesses in lack of referencing will not be corrected.

Baker, W. E., Westine, P. S., Kulesz, J. J., Wilbeck, J. S., and Cox, P. A., "A Manual for the Prediction of Blast and Fragment Loading on Structures," (1980), DOE/TIC-11268, U.S. Dept. of Energy, Amarillo, TX, Nov 1980. (Ref. 12)

This voluminous work is directed toward structural engineers who design blast-resistant structures for accidental explosions involving high explosives. Many graphs and equations, and many example problems are included. Topics covered are air blast from single and multiple high explosive sources, both bare and encased; blast loading of structures for internal and external explosions; cratering and ground shock for explosions in earth-covered structures; and a very detailed treatment of fragmentation and impact effects of fragments. General information is given on dynamic properties of construction materials and on methods for dynamic structural design. Referencing is thorough, and an extensive bibliography is also included.

DISCUSSION OF REFERENCE TEXTS

There are a number of reference texts which provide very useful information relating to nonnuclear weapons effects. But, very few give direct prediction methods for such effects. It is suggested that the reader study them primarily to try to understand the physics of the complex processes occurring, for information on computational and experimental methods, and as general background reading.

Zel'dovich, Ya. B., and Razier, Yu. P., *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena*, Vol. I, Academic Press, N.Y., 1966. (Ref. 13)

Zel'dovich, Ya. B., and Razier, Yu. P., *Physics of Shock Waves and High-Temperature Hydrodynamic Phenomena*, Vol. II, Academic Press, N.Y., 1967. (Ref. 14)

This two-volume work is a translation from the Russian. If you want to make a detailed study of the title topic, it is must reading. The treatment is very thorough, but also very readable. Reference to related work world-wide is thorough.

Johansson, C. H. and Persson, P. A., *Detonics of High Explosives*, Academic Press, London and New York, 1970. (Ref. 15)

"This is a thorough treatment of almost everything that is known about liquid and solid explosives. It should be the first source for anything you want to know. It also contains many excellent modern references." (W. C. Davis, in Ref. 5)

Cook, M. A., *The Science of High Explosives*, Reinhold, NY, 1958. (Ref. 16)

"Here we have many useful data, lots of phenomenology, and interesting pictures. Unfortunately, there is also a great deal of interpretation which is not accepted by other workers in the field, and a newcomer to the business has a hard time deciding what to believe and what to reject. My advice is to use it as a very valuable source of data, but to be careful about accepting the discussion and conclusions." (W. C. Davis, in Ref. 5)

Kinney, G. F. (1962), *Explosive Shocks in Air*, MacMillan, New York, New York. (Ref. 17)

For some years, this was one of the few readily available references on air blast waves. It evolved from a course taught by its author of the U. S. Naval Postgraduate School. But, the material is relatively superficial and does not at all reflect the breadth of experimental and analytical work which had been done before it was published. Literature citations are very limited. It has been supplanted by later and more comprehensive works.

Baker, W. E. (1973), Explosions in Air, University of Texas Press, Austin, Texas. (Ref. 18)

"Although this book will not satisfy all the requirements of either the casual, neophyte, or experienced investigator, it provides by far the most comprehensive treatment of the subject available in a single volume, and as such it offers something worthwhile to all. A good balance between theoretical and experimental approaches is maintained throughout the book with adequate mention of theoretical-experimental relationships and their importance to the understanding of the blast phenomena or solving practical explosion problems."

"Baker does a good job of describing many types of instrumentation in current use for laboratory or field applications. Mechanical, electro-mechanical, and piezoelectric gages are discussed. Mechanical, CRO, magnetic tape, and photographic systems and techniques for recording transducer output or blast phenomena directly are given adequate treatment."

"In light of the rapid changes in instrumentation available for researchers' use, it would have been well to devote a page or two to the requirements of a blast-measuring system. A curve showing frequency response requirements versus charge weight (or energy, the term Baker is prone to use) would have been quite helpful."

"The relatively large bibliography is a fine feature; the serious investigator is given guidance to sources in greater depth."

"All in all, Baker's Explosions in Air is a welcomed and noteworthy addition to a sparsely documented field." (J. F. Petes, book review)

Henrych, J. (1979), "The Dynamics of Explosion and Its Use", Amsterdam, Elsevier Scientific Publishing, (Ref. 19)

This book is a very useful reference work, but flawed. In some respects, it is encyclopedic, with coverage of many aspects of explosions of chemical high explosives and the effects of such explosions in air, water, and earth. Some treatment of nuclear explosions is also included. But, like an encyclopedia, coverage of some topics is shallow and does not reflect the depth of material available on these topics.

Topics which are well covered include the stress wave theory, detonations and close-in effects of explosions in high explosives, explosions in soils, underground blasting and cratering,

and response of elastic and elastoplastic structural elements to blast loading. Coverage of elastic vibrations of structures is particularly exhaustive. Topics covered in a more superficial manner include explosions in air, explosions in water, use of explosives in demolition and seismic effects of explosions. Scaling laws for explosions in air or water, which are essential to these topics, are barely mentioned.

As is probably natural for a book written in Czechoslovakia, references to work in eastern Europe and Russia are extensive, and the inclusion of such references is very valuable for western readers. But, many readily available references from the United States and other western world sources are lacking, and many of the references which are listed are now dated and superceded by later work. In general, there are too few references to work more recent than 1969.

The writing is clear and the exposition easy to follow, but in some instances, too much mathematical detail is included. We would have preferred to see less mathematical development and more experimental data verifying some of the theory.

In summary, this is a voluminous book containing much useful information on detonative explosions of chemical explosives, effects of these explosions, and a number of peripheral topics. But the reader is cautioned that the coverage is quite incomplete on some topics, and perhaps too detailed on other topics. References to good recent works in this field are also omitted.

Norris, C. H., Hansen, R. J., Holley, M. J., Biggs, J. M., Namyet, S. and Minami, J. V., Structural Design for Dynamic Loads, McGraw-Hill Book Co., NY, 1959. (Ref. 20)

This book first appeared as a set of course notes for a short course taught by MIT staff. Procedures carry over directly from an earlier U. S. Army Corps of Engineers manual. As with the Army manual, these methods reappear in many later manuals. It is an excellent introductory text for response of dynamically-loaded structures.

Biggs, J. M. (1964), Introduction to Structural Dynamics, McGraw-Hill Book Company, New York, New York. (Ref. 21)

This is an excellent introductory text for any engineer engaged in dynamic structural design. Biggs is one of the authors of the earlier Army Corps of Engineers manual, and Norris, et al. (Ref. 20). This book draws heavily on the earlier work, but adds considerable material. Presentation is very clear and understandable.

Baker, W. E., Cox, P. A., Westine, P. S., Kulesz, J. J., and Strehlow, R. A., Explosion Hazards and Evaluation, Elsevier Scientific Publishing Co., Amsterdam, 1983. (Ref. 22)

This new book discusses a variety of types of explosion sources, and presents methods for estimating air blast loads on and within structures,

some classes of fragment formation and impact effects, simplified and more complex methods of predicting structural response and damage from blast loading, and thermal radiation effects from nonnuclear explosions. Referencing is thorough, and there is an extensive bibliography. A number of example problems illustrate the prediction methods.

Goldsmith, W., *Impact, The Theory and Behavior of Colliding Solids*, Edward Arnold, Ltd, London, 1960. (Ref. 23)

This text gives very thorough coverage of the title topic, both theory and experiment. If you have any interest in the elastic and plastic processes involved when solids collide, you should have this book on your shelf (or desk). The references to the literature are as complete as you could hope to find. [In fact, the earliest reference starts, "Galilei, G.... (1638)."] It seems unlikely that Professor Goldsmith missed any significant references to this topic between 1638 and 1960!]

Zukas, J. A., Nicholas, T., Swift, H. F., Grassczuk, L. B., and Curran, D. R., *Impact Dynamics*, John Wiley & Sons, New York, 1982. (Ref. 24)

In recent years, the power of new computers has allowed numerical solutions to the complex sets of differential equations, describing the impact, and resulting deformation and penetration processes occurring in high-speed impacts. Experimental methods have also advanced to allow some observation of the dynamics of these very fast processes. This book covers both of these aspects of high-speed impact quite well. If you are interested in modern technology in this field, you should get this book. Presentation is graphic and clear, and all sources are well referenced.

Backman, M. E., *Terminal Ballistics*, NWC TR 5780, Naval Weapons Center, China Lake, CA, Feb 1976. (Ref. 25)

This book is in reality a report, but it is included because of its direct applicability to nonnuclear weapons effects. It is a primer in ballistics, and as such does not go deeply into any topic. It should make good initial reading for the neophyte, but it should be quickly supplemented by more detailed references. The reference list in the report is quite limited.

Cole, R. H., *Underwater Explosions*, Princeton University Press, Princeton, NJ, 1948 (Reprinted by Dover Publications, 1965). (Ref. 26)

This is an example of a reference which is truly unique in a field. Cole's book covered U.S. and British research, both analytic and experimental, on underwater explosions during World War II. There is no other comparable reference on this topic, and much of the material in it is as useful now as in 1948. Swisdak's compendium (Ref. 4) adds some newer work, but also relies very heavily on Cole's book. If you are interested in underwater explosions, you must get a copy of this book.

Baker, W. E., Westins, P. S. and Dodge, F. T., *Similarity Methods in Engineering Dynamics*, Hayden Book Co., New Rochelle, NJ, 1973. (Ref. 27)

The predecessor to this book was a set of notes for a short course on scale modeling of weapons effects. The book is expanded considerably beyond that scope, but it contains chapters on scaling of air blast waves and impact forces, scaling of dynamic elastic and plastic response of structures, scale modeling of penetration mechanics, modeling of rigid-body dynamics of structures, and scaling of cratering from buried explosions. The reference list is thorough.

There are a number of example problems, keyed to individual chapters.

CLOSURE

The limited list of broad references reviewed in this paper have, for the most part, proved very useful to staff members at Southwest Research Institute in prediction and evaluation of a number of conventional weapons effects, even though only a few of them were intended for that purpose. We have found that having a reference shelf with general, unclassified references of this kind is often far more valuable than having many file cabinets full of classified references.

Let us comment on the availability of the 27 general references on our list. Those which have an accession number for National Technical Information Services (NTIS) are readily available at a nominal cost, and we have given those numbers which we know. Procedures for obtaining the design manuals are often more difficult. You must usually contact the sponsor for the manual preparation and beg for a copy. Obtaining the newer reference texts in our list is not difficult, provided you are willing to pay the (sometimes outlandish) purchase price. Any published more than 10 years ago are probably out of print, and thus obtaining a copy can be quite difficult. Unfortunately, for a few very useful references such as Refs. 2 and 5, extra copies are now almost impossible to obtain, and you must rely on friendship with someone who happens to have access to a few spare copies.

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